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STACK MIL04

Power Usage Effectiveness Technical Note

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EXECUTIVE SUMMARY

MIL04 is a new build data centre, located in the Vellezzo Bellini municipality, South West of Milan, Italy. The site plan consists of a plot area of around 76,700 m².

This site consisting of:

a. Substation,
b. Three data centre buildings,
    a. Building A (10 MW_{IT}),
    b. Building B (20 MW_{IT}),
    c. Building C (10 MW_{IT}),
c. Sitewide fire hydrant pump room.

There is a potential reserve capacity building (Building D), however, it has not been included as part of the scope of this document.

Black & White Engineering has been appointed to evaluate the designed power usage effectiveness (dPUE) for MIL04 in accordance with EN 50600-4 and ISO/IEC 30134-2:2016/AMD 1:2018. The target dPUE is set to be lower or equal to 1.4. This technical study demonstrates how the annualised PUE has been derived for MIL04 and outlines all the basis of calculations.

Photovoltaic (PV) has also been discussed in this report. Although alternative energy systems such as PV, wind, solar thermal, should not be included in the PUE calculation, their potential positive impact to the PUE have been evaluated separately for completeness.

The PUE analysis conducted shows that the predicted annualised dPUE at 100% IT load utilisation is 1.252 based on ASHRAE weather data. However, it is extremely rare for data centres to be operating at a constant 100% IT utilisation for the entire year. It is more likely to be operating at 50% to 75% IT utilisation and therefore a more realistic aPUE of 1.23 is expected.

With the aid of PV power output, it can potentially bring the theoretical PUE down by 0.003 subject to the solar irradiance and actual IT utilisation.

Designed PUE summary:

	100% IT load
Annualised dPUE	1.252
Annualised dPUE with PV generation	1.249

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ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Abbreviation	Meaning
ACC	Air-cooled chiller
AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD	Computational fluid dynamics
CHW	Chilled water
CRAH	Computer room air handling
DB	Dry bulb
DP	Dew point
DX	Direct expansion
EER	Energy efficiency ratio
ERE	Energy reuse effectiveness
EU	European Union
FWU	Fan wall unit
HC	Hybrid cooler
IT	Information technology
IWEC	International weather for energy calculations
LV	Low voltage
MMR	Meet me room
MV	Medium voltage
PDU	Power distribution unit
PUE	Power usage effectiveness
PV	Photovoltaic
STS	Static transfer switch
UPS	Uninterrupted power supply
VRF	Variable refrigerant flow
VSD	Variable speed drive
WB	Wet bulb

Symbol	Meaning
E	Energy consumption

Subscript	Meaning
C	Cooling capacity
DC	Data centre
IT	Information technology
TH	Thermal

1.0 INTRODUCTION

1.1 Overview

There is a heavy focus on energy efficiency in the data centre industry and the measure of Power Usage Effectiveness (PUE) is used to evaluate how effectively the power is used in generating IT capacity. PUE is essentially the ratio of the data centre total energy consumption to IT equipment energy consumption, calculated and measured across the same period.

As the PUE value is always greater than 1, an efficient annualised value is deemed to be between 1.2 – 1.5 with anything below this range seen as very efficient (see Table 1.1). A recent survey published by the Uptime Institute indicated that the average annualised PUE globally was 1.57, however, it is noted that this figure included many older data centres where it was not possible to overhaul the facility to achieve better efficiencies.

Table 1.1: Levels of efficiency based on PUE

PUE	Level of efficiency
3.0	Very inefficient
2.5	Inefficient
2.0	Average
1.5	Efficient
1.2	Very efficient

The target designed PUE (dPUE) for MIL04 is to be less than or equal to 1.4. This target indicates an highly efficient data centre power usage and is in line with the current growing trend of lowering PUEs. To achieve this dPUE, there are many factors that contribute to it such as equipment selections, equipment efficiencies, distribution losses, and one of the key dPUE contributors is the mechanical cooling of IT equipment and the temperatures associated with this cooling. This report aims to describe how the annualised dPUE for MIL04 was calculated in accordance with internationally recognised standards such as the Green Grid, EN 50600-4 and ISO/IEC 30134-2:2016/AMD 1:2018.

1.2 The Site

MIL04 is a new build datacentre in the Vellezzo Bellini municipality, in the Province of Pavia in the Italian region Lombardy, located about 25 km south of Milan. The site plan consists of a plot area of around 76,700 m².

Figure 1.1: Site location[1]

[1] Google map data (2022*) GeoBasis-DE/BKG (@2009)*. Available at: http://maps.google.co.uk (Accessed: 05 October 2023).

Figure 1.2: Rendered image of the proposed Datacentre building

There are three main data centre buildings within the site (Building A to C), each building consists of:

a. Ground Floor: data halls, with external generator compartments and mechanical plant rooms,
b. First floor (mezzanine level): electrical plant rooms
c. Roof: heat rejection plant,
d. Admin support building.

1.3 Weather Data

ASHRAE International Weather for Energy Calculations version 2.0 (IWEC2) typical year hourly data is used for the annualised PUE calculations. This data is derived from meteorological reports of weather stations from Milano Linate (the nearest weather station available) that has been archived in the Integrated Surface Hourly (ISH) data base maintained by the National Climatic Data Center (NCDC).

The graphs below represent the annual dry bulb and wet bulb temperature profiles.

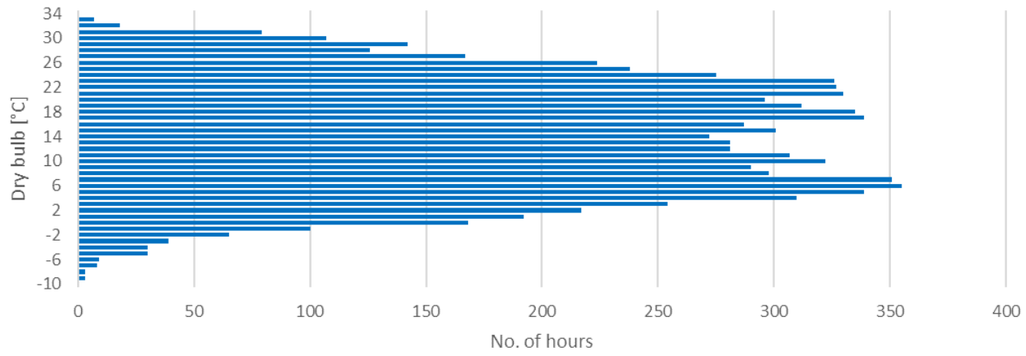


Figure 1.3: Annual dry bulb temperature profile

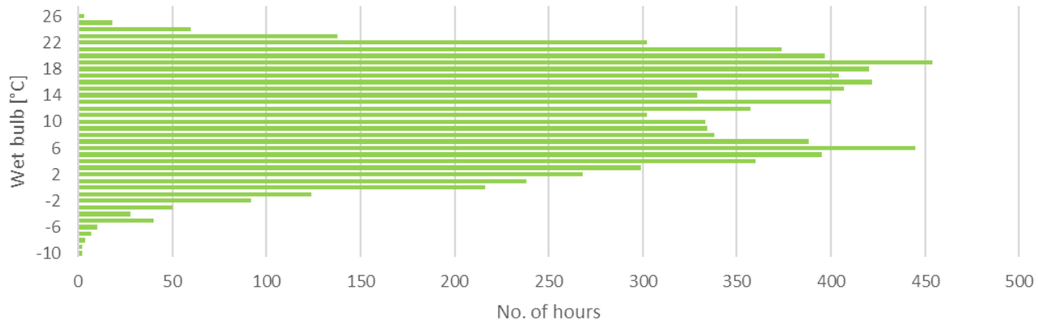


Figure 1.4: Annual wet bulb temperature profile

Outdoor design conditions are based on ASHRAE 2021 weather data for the location of Milano Linate, Italy. Extreme annual design data of n=20 years will be used for peak load calculations and equipment selections in critical areas, highlighted in Figure 1.5. Complete set of data available in Appendix A.

Extreme Annual Design Conditions																
Extreme Annual WS				Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature								
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years		
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
6.8	5.4	4.4	DB	-6.4	35.5	2.0	1.3	-7.8	36.5	-9.0	37.2	-10.1	37.9	-11.5	38.8	
			WB	-7.0	26.1	2.0	1.4	-8.5	27.1	-9.6	28.0	-10.8	28.7	-12.2	29.8	

Figure 1.5: Milano Linate ASHRAE 2021 Extreme Annual Design Conditions

Due to climate change, it is expected the maximum dry and wet bulb temperatures will continue to increase and with equipment service life to be approximately 15-20 years, it is sensible to select equipment rating based on minimum n=20-years conditions.

It should be noted that the weather data does not account for any additional heat island effect within the roof caused by warm air recirculation from the heat rejection plant. Based on the computational fluid dynamics (CFD) modelling results, a +1.7°C uplift in dry bulb (DB) temperature has been observed. Therefore an additional +1.7°C DB has been allowed for in the calculation and equipment selection.

1.4 Basis of Design

This study has been carried out based on the following key design criteria and building site constraint.

Table 1.2: Key design criteria

Design Criteria		
Peak external design conditions	Summer: Winter:	37.9°C dry bulb (DB), 28.7°C wet bulb (WB) -10.1°C DB, -10.8°C WB
Internal design conditions	Data halls/Network rooms	Normal Operation: ASHRAE Recommended range of up to 27°C DB, 5.5 – 15 °C dew point (DP) Maintenance/failure: ASHRAE A1 range of up to 32 °C DB
	Electrical Rooms	Normal Operation: 28 °C , Maintenance/failure of 1no. CRAH: 28 °C
Chilled Water (CHW) System Temperature	Flow: Return:	20 °C 30 °C
Cooling Capacity	Total IT: Total Thermal:	40 MW_{IT} 46.8 MW_C
Mechanical Redundancy	Cooling modules	N+1
	Data hall cooling units	N+3
Electrical Power Module		1.2 MW_{IT}
Generators		2.25 MW_e
Electrical Redundancy		Distributed redundancy, 5N6

1.4.1 Data Hall Internal Environment Conditions

Internal environment conditions are of importance to IT and electrical hardware and equipment due to its sensitivity to temperature and humidity level can impact the static charge voltage in the air. ASHRAE Thermal Guidelines for Data Processing Environments TC 9.9 has outlined the recommended internal conditions for data centre operation in order to improve the usable life cycle of the equipment and its thermal compatibility and reliability.

The ASHRAE recommended and A1 allowable range are highlighted in the image below. Data centre facilities are designed and operated to the target the recommended range during normal operation. During maintenance, failure mode or extreme weather conditions, the data centre facilities are permitted to operate in the A1 Allowable range for a limited period.

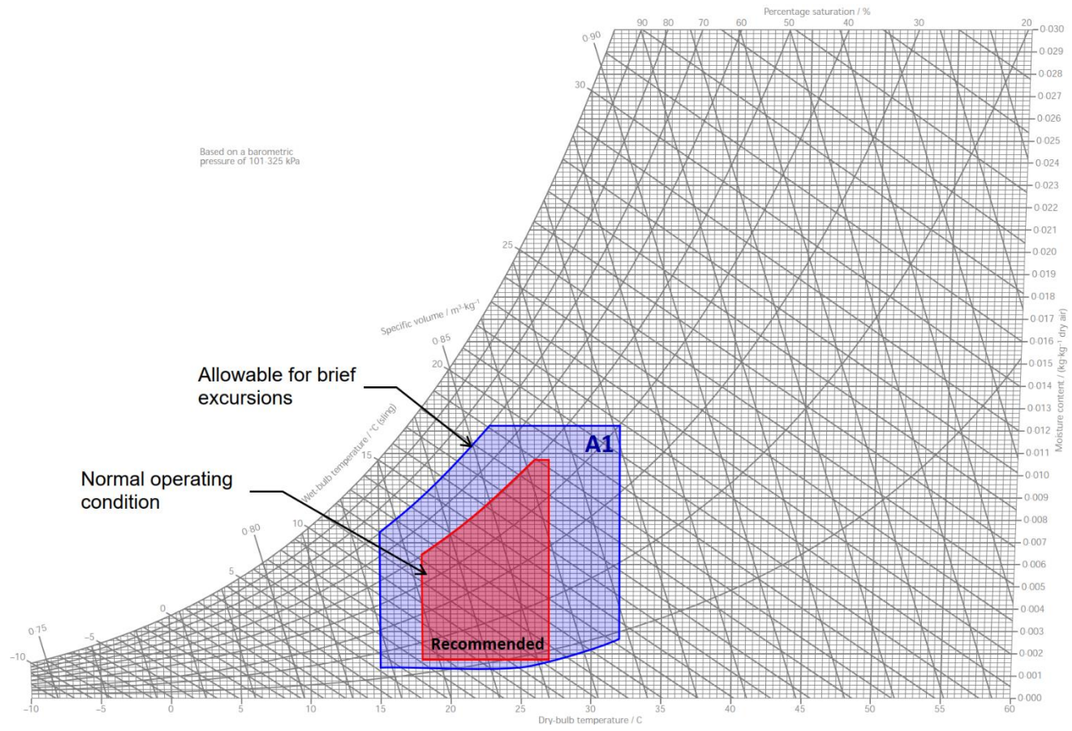

Based on a barometric pressure of 101 325 kPa
Allowable for brief excursions
Normal operating condition
A1
Recommended
Percentage saturation / %
Specific volume / m³·kg⁻¹
Wet-bulb temperature / °C (sling)
Dry-bulb temperature / °C
Moisture content / (kg·kg⁻¹ dry air)

Figure 1.6: Class A1 allowable and recommended operating conditions (adapted from ASHRAE TC9.9).

2.0 COOLING TECHNOLOGIES

2.1 Overview

The proposed cooling system comprises the following primary components:

1. Heating rejection by means of air cooled chillers,
2. Primary chilled water (CHW) pumps with variable speed drive (VSD),
3. Fan wall units (FWU) in data halls,
4. Computer room air handling (CRAH) units in electrical switchrooms,
5. DX units in network rooms for resilience.

In order to meet the ASHRAE recommended internal operating conditions and maintaining appropriate room temperature for the electrical switch rooms, the design CHW system temperature is set to 20°C flow and 30°C return. This allows the fan wall unit design supply air temperature to be set at 24-25°C.

The entire site is designed to deliver IT load of 40 MW_{IT} in total, and the overall cooling load is approximately 47 MW_C. Each primary CHW circuit has a total cooling capacity of 1.184 MW_C which supports 1 MW_{IT} load plus the additional ancillary load from the electrical equipment.

Table 2.1: Critical cooling strategy

Total IT Capability (per circuit)	Total Cooling Capacity (per circuit)	Cooling & Heat Rejection Plant
1 MW_{IT}	1.184 MW_c	Air cooled chiller at 1.184 MW each supports three fan wall units (with gross cooling capacity of 358.7 kW each) and the electrical switch rooms CRAH units

Refer to Appendix B for the primary CHW schematic.

3.0 PUE ANALYSIS

3.1 Methodology

The dPUE calculations have been conducted in accordance with the European standards EN 50600-4, and international standards ISO/IEC 30134-2:2016/AMD 1:2018 and it has been analysed under various levels of IT utilisation, ranging from 25 % to 100 %.

Designed power usage effectiveness is the ratio of the data centre total energy consumption to the IT equipment energy consumption.

$$dPUE = \frac{E_{DC}}{E_{IT}} \quad (1)$$

where

E_{DC} total data centre energy consumption (annual) in kWh
E_{IT} IT equipment energy consumption (annual) in kWh

The E_{IT} used in the calculation includes the energy consumed by IT equipment (e.g. storage, processing, network data)

The E_{DC} includes E_{IT} plus all the energy that is consumed to support the following:

1. Power system, including UPS systems, switchgear, generators, power distribution units (PDUs), batteries, and distribution losses external to the IT equipment.
2. Cooling system, including heat rejection plant (air cooled chillers), pumps, fan wall units (FWU), computer room air handling units (CRAHs), air handling units (AHUs).
3. Others including data centre lighting, elevators, security systems, and fire alarm/detection systems.

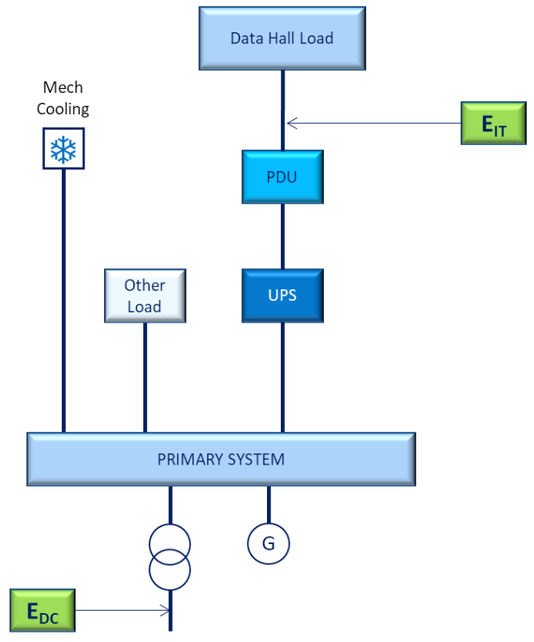


Figure 3.1: E_{DC} and E_{IT} definition

3.1.1 Monitoring and metering locations

Figure 3.2 shows the E_{DC} is measured after the utility feed at the metering point, M1, and the metering point, M2, at the PDUs is used to determine the IT equipment load. Optional metering points may be added subject to customer requirements to monitor the consumption of other data centre loads.

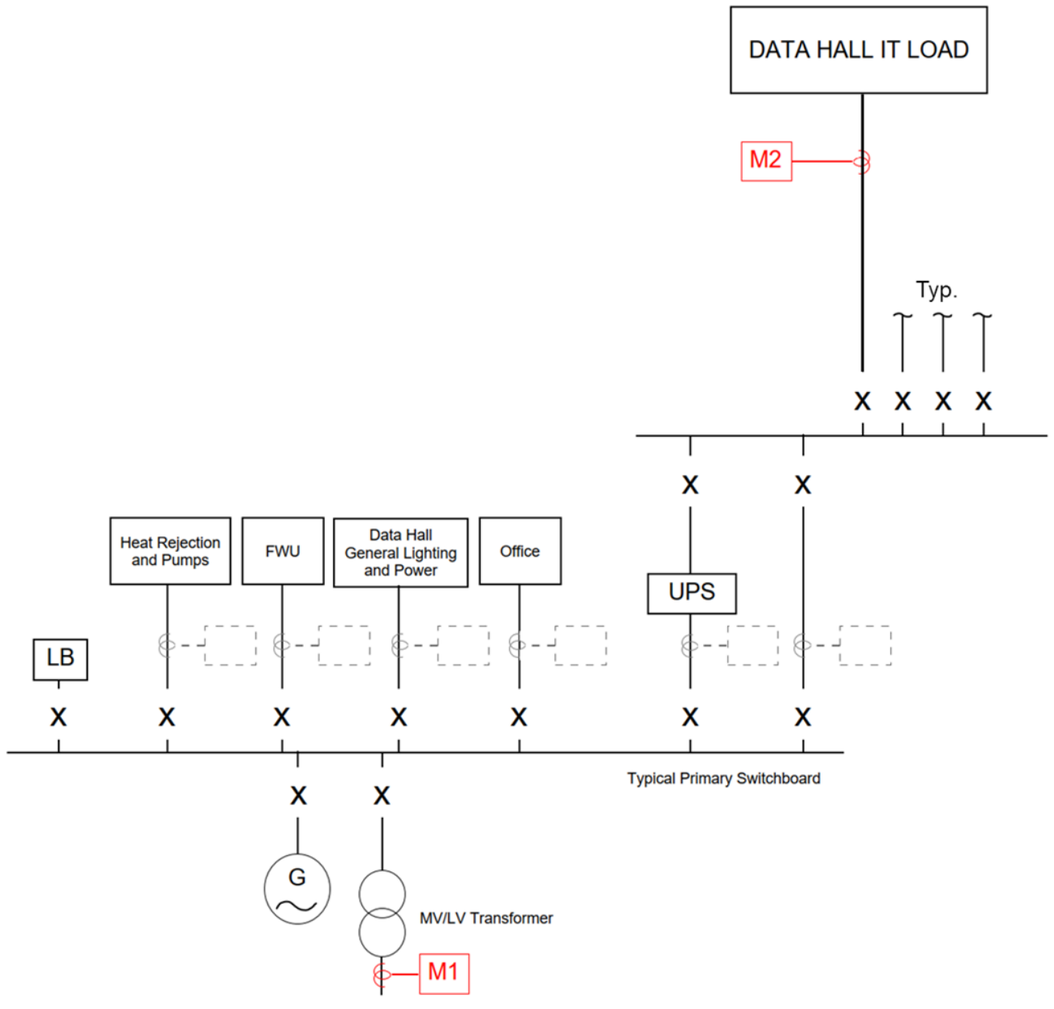


Figure 3.2: Typical metering strategy

3.2 Detailed Annualised PUE Analysis

The table below shows the estimated annual energy consumption of the data centre site to support maximum 40 MW_{IT} load per phase, further estimation of the building energy consumption under different IT utilisation has also been included.

Table 3.1: Annual dPUE contribution (critical equipment) supporting 40 MW_{IT} load.

	Annual Power Consumption (kWh)							
Equipment Description	**100% IT load**		**75% IT load**		**50% IT load**		**25% IT load**	
Critical Cooling (@N+1)	35845213	(0.1023)	26883910	(0.1023)	17922607	(0.1023)	8961303	(0.1023)
CHW pumps (@N+1)	4400957	(0.0126)	3259968	(0.0124)	2514833	(0.0144)	1872748	(0.0214)
Frost protection	54428	(0.0002)	136070	(0.0005)	272141	(0.0016)	408211	(0.0047)
Fan wall units (@N+2)	16863000	(0.0481)	7114078	(0.0271)	2107875	(0.0120)	263484	(0.0030)
CRAH (@N+1)	1256184	(0.0036)	1256184	(0.0048)	1256184	(0.0072)	1256184	(0.0143)
Air handling units (@N+1)	336384	(0.0010)	336384	(0.0013)	336384	(0.0019)	336384	(0.0038)
Humidity control (@N+1)	249616	(0.0007)	249616	(0.0009)	249616	(0.0014)	249616	(0.0028)
DX & VRF systems	336384	(0.0010)	336384	(0.0013)	336384	(0.0019)	336384	(0.0038)
IT UPS Losses	12964800	(0.0370)	8672400	(0.0330)	5606400	(0.0320)	3153600	(0.0360)
Reserve UPS losses	280320	(0.0008)	280320	(0.0011)	280320	(0.0016)	280320	(0.0032)
Electrical Distribution Losses	3113646	(0.0089)	1992733	(0.0076)	778411	(0.0044)	194603	(0.0022)
Mech. UPS Efficiency	855765	(0.0024)	441949	(0.0017)	223398	(0.0013)	128912	(0.0015)
General Ltg & SP consumption (Admin building + DC)	6879537	(0.0196)	6879537	(0.0262)	6879537	(0.0393)	6879537	(0.0786)
MV / LV Transformer Losses	4916811	(0.0140)	2629244	(0.0100)	1497749	(0.0085)	872986	(0.0100)
Annualised dPUE		**1.252**		**1.230**		**1.230**		**1.288**

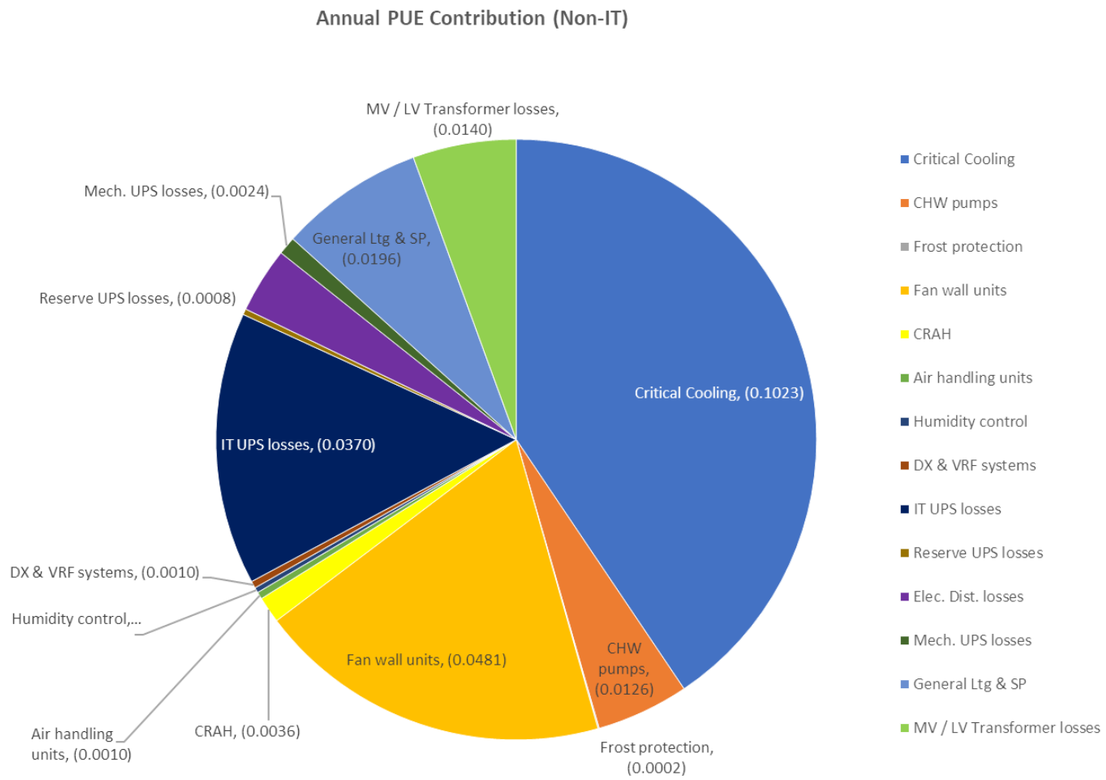


Figure 3.3: Annual dPUE contribution based on air cooled chiller at 100% IT utilisation.

Notes:

1. The calculation has been carried out based on the assumption of constant IT, i.e. no fluctuation throughout the year. Whilst this is an unrealistic situation, it helps simplify the calculation and creates a better direct comparison between the different scenario stated above.
2. The calculation is based on the assumption of normal operation conditions (i.e. no failures) for the entire annual period.
3. On the basis of Note 2, charging current of the UPS has been omitted.
4. Load relating to datacentre operation has been considered for the PUE calculation, including the following:
    a. UPS Losses
    b. Critical chilled water infrastructure relating to the data halls, switchrooms and network rooms only.
    c. Associated services for the operation of the critical load: general lighting and power to critical areas and controls load.
    d. Datahall pressurisation.
    e. Generator auxiliary systems' loads.
    f. Physical Security.
    g. Landlord load (including fire detection system, general lighting and small power, security systems, elevators).
5. Annual hourly data is based on the ASHRAE International Weather data for Energy Calculations version 2 (IWEC2) weather file for Milano Linate, the nearest IWEC2 data to Vellezzo.
6. Designed PUE Calculations are based on pre-construction and procurement level of information.
7. Designed PUE calculations are based on generic equipment selections and do not represent final procured equipment.
8. Designed PUE calculation is based on EN 50600-4 and industry general standard operating procedures.
9. Design is based on 40 MW of IT capacity, with no tape store.
10. Design is based on IT room delta T of 11 °C.
11. Transformer losses are based on the load and no-load losses in EU Eco Design Requirements 548/2014, Annex 1, Minimum energy performance or efficiency requirements for medium power transformers, Tier 2 transformers.
12. The general lighting and small power load has been calculated based on the buildings being manned during normal working hours with daylight dimming and PIR sensor control being taken into accounted (except for the security room where it will be operating at all time).

3.2.1 Annual hourly data on heat rejection plant

The table below shows the energy demand of the heat rejection plant with hourly data across the year for Building A (i.e. 10 MW_{IT}). Further information can be found in Appendix D.

Table 3.2: Annual hourly data of ACC energy consumption

Temperature (°C)	Operation hours	Free cooling capacity per chiller (kW)	No. of active compressors (%)	ACC Abs Power (kWh)
-10.0	2	1000	-	286
-9.0	3	1000	-	438
-8.0	4	1000	-	603
-7.0	8	1000	-	1225
-6.0	12	1000	-	1889
-5.0	30	1000	-	4798
-4.0	33	1000	-	5400
-3.0	47	1000	-	7865
-2.0	70	1000	-	11962
-1.0	108	1000	-	18910
0.0	179	1000	-	32233
1.0	192	1000	-	35910
2.0	221	1000	-	43440
3.0	265	1000	-	63620
4.0	318	1000	-	117506
5.0	344	1000	-	137346
6.0	389	1000	-	172730
7.0	328	1000	-	179737
8.0	290	758.3	30 | -	217991
9.0	299	742.5	32 | -	228245
10.0	340	725.1	34 | -	265440
11.0	279	706.4	36 | -	223608
12.0	291	686.4	38 | -	236996
13.0	278	665.6	40 | -	232927
14.0	278	644.9	43 | -	241897
15.0	299	623.7	45 | -	273017
16.0	307	601.1	48 | -	302462
17.0	354	564.8	53 | -	384512
18.0	321	521	60 | -	387377

Temperature (°C)	Operation hours	Free cooling capacity per chiller (kW)	No. of active compressors (%)	ACC Abs Power (kWh)
19.0	309	477.5	67 | -	418834
20.0	307	425.4	75 | -	478376
21.0	321	369.6	85 | -	569483
22.0	346	316.7	95 | -	642566
23.0	282	295.4	50 | 50	486212
24.0	285	253.5	50 | 50	496732
25.0	235	209.4	50 | 50	414144
26.0	192	161.8	50 | 50	352968
27.0	156	0	51 | 75	316365
28.0	134	0	53 | 75	281000
29.0	135	0	54 | 75	291498
30.0	96	0	56 | 75	214020
31.0	58	0	57 | 75	132878
32.0	12	0	59 | 75	28562
33.0	3	0	61 | 75	7300
			Total	**8961303 kWh**

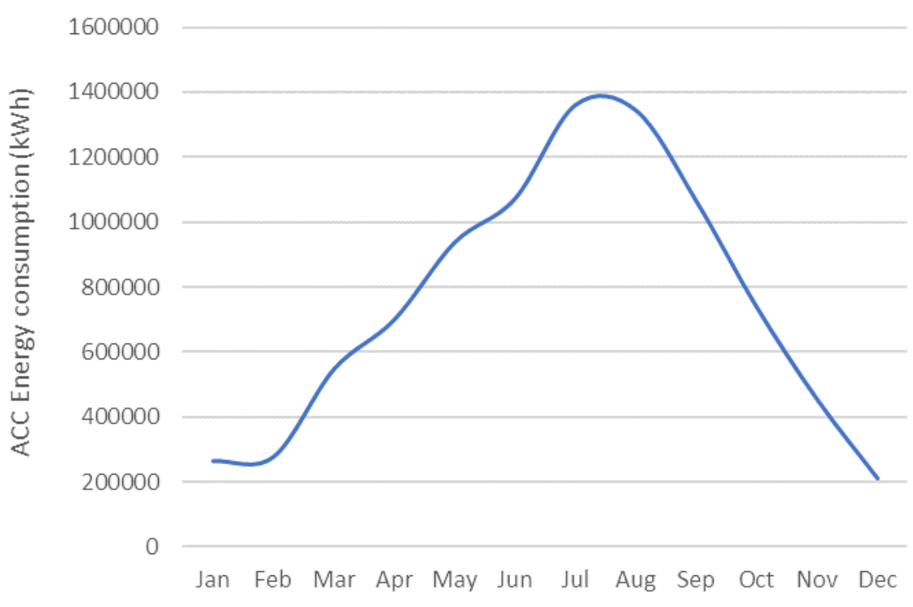


Figure 3.4: Air cooled chillers annual power consumption profile for Building A

3.3 Detailed Peak PUE Calculation

The peak designed PUE calculation has been carried out based on external ambient temperature of 37.9°C DB, 28.7°C WB, with an uplift of 1.7°C DB due to hot air recirculation around the chillers. This uplift in air temperature has been observed in the CFD analysis and further details can be found in 3604 EY RE 03. This calculation is based on the assumption of no system failure and no planned maintenance, at 100% IT load.

Table 3: Peak designed PUE

Equipment Description	Peak Power Consumption (kW)	
Critical Cooling (@N+1)	12715	(0.318)
CHW pumps (@N+1)	502	(0.013)
Fan wall units (@N+3)	1925	(0.048)
CRAH (@N+1)	143	(0.004)
Air handling units (@N+1)	38	(0.001)
IT UPS Losses	1480	(0.037)
Reserve UPS losses*	32	(0.001)
Electrical Distribution Losses	155	(0.004)
Mech. UPS Efficiency	98	(0.002)
General Ltg & SP consumption (Admin building + DC)	246	(0.006)
MV / LV Transformer Losses	650	(0.016)
TOTAL	**17985**	**1.450**

The peak designed PUE has been determined as 1.45.

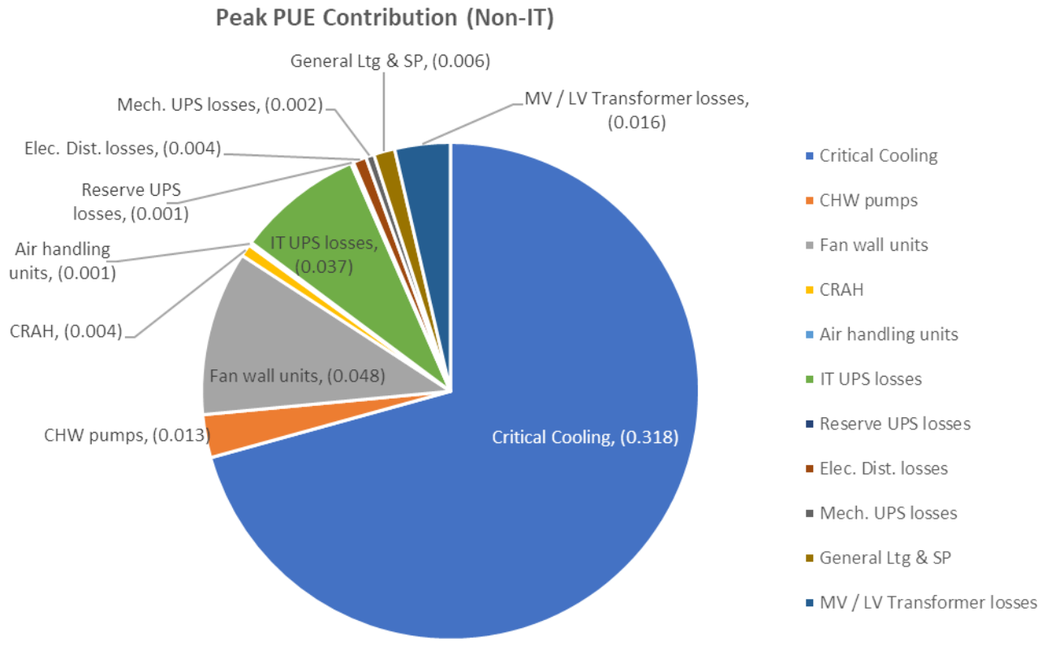


Figure 3.5: Peak dPUE contribution diagram

3.4 Photovoltaic

The site will be benefited from "green" power generation from photovoltaic (PV) and all of the power generated will be exported to the grid.

There is a total of approximately 5200 m² of PV panels space been allocated across the site, located at roof level (see Figure 3.6).

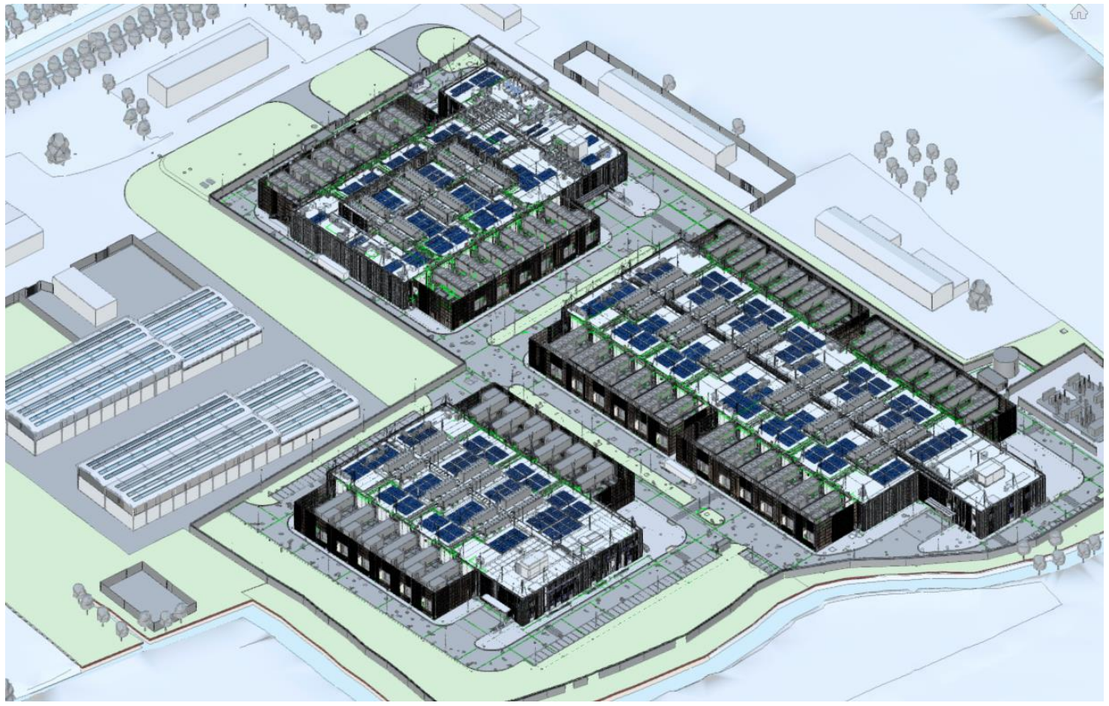


Figure 3.6: Proposed PV panel locations

The estimated power generation from the PV panels is approximately 1,149,800 kWh/year. This is based on the average monthly solar irradiance data in Milan and all the roof mounted PV panels to have an inclination of 5°. The table below shows the estimated monthly average energy yield across the three buildings.

Table 3.4: Monthly average energy yield from PV in kWh

Panel location	Monthly average energy yield from PV (kWh)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Building A	8937	12848	22893	31995	38853	47099	45866	35974	27615	16180	8773	8033
Building B	17916	24630	41484	54234	62558	78199	75792	59065	52952	28450	14389	14319
Building C	10914	15048	25400	33218	38331	47850	46413	36162	32518	17392	8808	8737

The PV power generation calculations are detailed within the Photovoltaic plant report ref 3604 ES D RE 05 by L22 and has been verified based on the European Commission Photovoltaic Geographical Information System (PVGIS).

The calculated peak PV power is based on the following method as suggested by PVGIS.

$$Peak\ PV\ power = Maximum\ PV\ panel\ power\ output\ \times area \times efficiency \quad (2)$$

where

Max. PV power output is obtained from manufacturer in kW/m²
Area measured in m²
Efficiency obtained from manufacturer in %

Table 3.5: Input data:

Panel location	Azimuth (°)	Inclination (°)	Estimates area (m²)	Losses	Calculated peak PV power (kW_p)
Building A	71	5	1500	26.1%	333
Building B	-19	5	2230	26.1%	504
Building C	-19	5	1370	26.1%	308

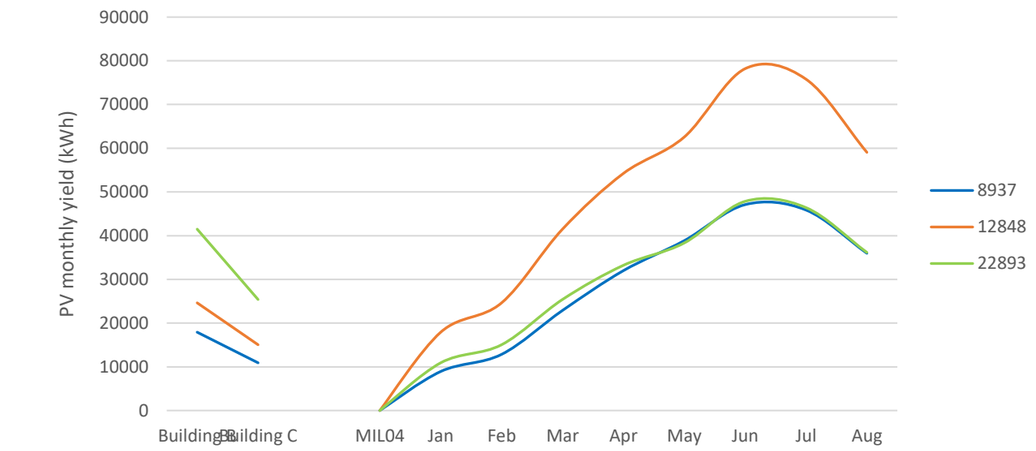


Figure 3.7: PV monthly energy yield across the three buildings

With the aid of these sustainable energy measures, the dPUE can 'theoretically' be further improved as shown in the table below. Note that the "improved" dPUE based on PV power input is outside of the EU standard calculation method.

Table 3.6: Improved theoretical PUE if PV power generation is included in the analysis.

	100% IT load	75% IT load	50% IT load	25% IT load
dPUE without PV	1.244	1.225	1.225	1.281
Improved annualised dPUE	1.241	1.221	1.218	1.268

4.0 CONCLUSION

The PUE analysis conducted shows that the annualised dPUE at 100% IT load utilisation is 1.252 based on ASHRAE weather data.

The peak dPUE at 100% IT load is 1.45.

However, it should be noted that under normal operation, data centre rarely reaches a constant 100% IT utilisation for the entire year. Based on past operational experience, STACK has never seen operating power levels exceed 80% and generally be operating between 50% to 75% IT utilisation. Therefore it is expected that the aPUE would be approximately 1.23 in reality.

Table 4.1: Designed PUE summary

	100% IT load	75% IT load	50% IT load	25% IT load
Peak dPUE	1.450	-	-	-
Annualised dPUE	1.252	1.230	1.230	1.288
Annualised dPUE with PV generation	1.249	1.226	1.223	1.274

With the aid of PV power output, it can potentially improve the dPUE marginally subject to the solar irradiance and actual IT utilisation.

Under initial phase, data centre typically operates at a much lower IT utilisation before ramping up to its design load, and during this temporary period, it should be expected that the aPUE will be higher than normal.

Appendix A ASHRAE Weather Data

ASHARE Weather data 2021, based in Milano Linate, Italy (WMO: 160800).

2021 ASHRAE Handbook - Foundamentals (SI)

MILANO LINATE, ITALY (WMO: 160800)

Lat:**45.445N** Long:**9.277E** Elev:**108** StdP: **100.04** Time zone:**1.00 (EUC)** Period:**94-19** WBAN:**99999**

Annual Heating, Humidification, and Ventilation Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		WSF
			99.6%			99%			0.4%		1%				
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
1	**-4.0**	**-2.7**	**-11.1**	**1.5**	**4.2**	**-8.6**	**1.8**	**3.2**	**9.0**	**9.0**	**7.5**	**8.9**	**0.9**	**190**	**0.385**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	**10.5**	**33.7**	**23.8**	**32.2**	**22.9**	**31.0**	**22.3**	**25.2**	**31.2**	**24.2**	**30.0**	**23.3**	**29.0**	**2.3**	**230**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Extreme Max WB
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
23.3	**18.4**	**28.5**	**22.3**	**17.2**	**27.4**	**21.4**	**16.3**	**26.6**	**77.5**	**31.2**	**73.3**	**29.9**	**69.9**	**28.9**	**29.0**

Extreme Annual Design Conditions

Extreme Annual WS				Extreme Annual Temperature				n-Year Return Period Values of Extreme Temperature							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
6.8	**5.4**	**4.4**	DB	**-6.4**	**35.5**	**2.0**	**1.3**	**-7.8**	**36.5**	**-9.0**	**37.2**	**-10.1**	**37.9**	**-11.5**	**38.8**
			WB	**-7.0**	**26.1**	**2.0**	**1.4**	**-8.5**	**27.1**	**-9.6**	**28.0**	**-10.8**	**28.7**	**-12.2**	**29.8**

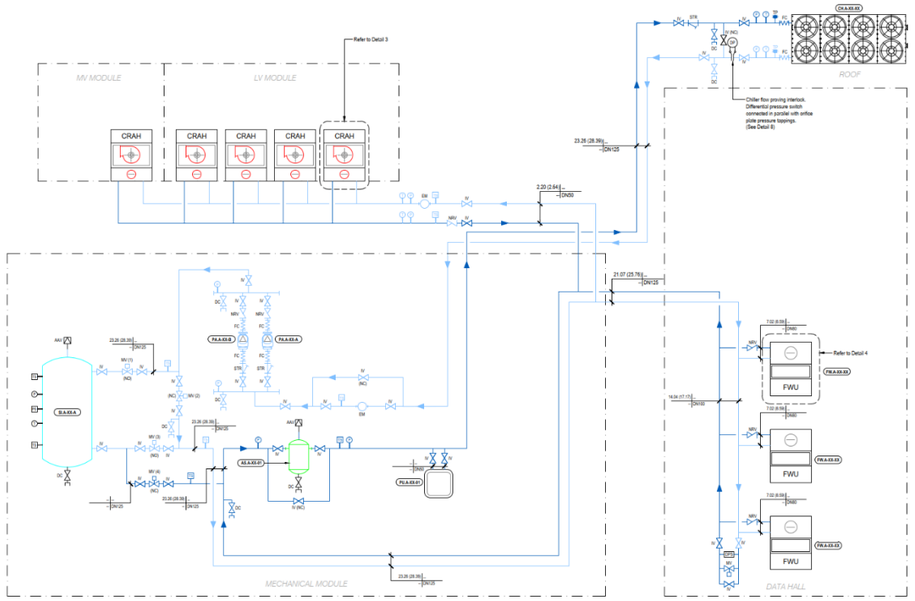
Monthly Climatic Design Conditions

		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	DBAvg	**14.5**	**3.7**	**5.6**	**10.2**	**14.1**	**18.8**	**23.1**	**25.2**	**24.6**	**20.1**	**14.9**	**9.0**	**4.3**
	DBStd	**8.14**	**2.64**	**3.09**	**3.27**	**3.04**	**3.07**	**3.10**	**2.31**	**2.60**	**2.82**	**3.15**	**3.25**	**2.99**
	HDD10.0	**598**	**195**	**125**	**37**	**4**	**0**	**0**	**0**	**0**	**0**	**3**	**56**	**178**
	HDD18.3	**2068**	**453**	**356**	**252**	**131**	**32**	**3**	**0**	**0**	**14**	**112**	**281**	**436**
	CDD10.0	**2249**	**1**	**2**	**44**	**126**	**273**	**393**	**472**	**453**	**304**	**156**	**25**	**1**
	CDD18.3	**677**	**0**	**0**	**0**	**3**	**46**	**146**	**213**	**194**	**68**	**7**	**0**	**0**
	CDH23.3	**6120**	**0**	**0**	**4**	**31**	**359**	**1336**	**2133**	**1801**	**433**	**22**	**0**	**0**
	CDH26.7	**2248**	**0**	**0**	**0**	**3**	**84**	**489**	**859**	**713**	**97**	**2**	**0**	**0**
Wind	WSAvg	**1.6**	**1.4**	**1.5**	**1.9**	**2.0**	**2.0**	**1.9**	**1.8**	**1.5**	**1.4**	**1.2**	**1.3**	**1.2**
Precipitation	PrecAvg	**971**	**75**	**66**	**82**	**79**	**93**	**71**	**60**	**84**	**72**	**105**	**98**	**60**
	PrecMax	**1413**	**275**	**151**	**202**	**244**	**289**	**153**	**203**	**178**	**214**	**417**	**265**	**156**
	PrecMin	**689**	**1**	**1**	**5**	**6**	**4**	**22**	**14**	**1**	**3**	**3**	**1**	**0**
	PrecStd	**225**	**65**	**45**	**54**	**55**	**70**	**34**	**49**	**56**	**58**	**93**	**64**	**35**
Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures	0.4% DB	**14.5**	**18.0**	**23.2**	**26.2**	**31.4**	**34.7**	**34.8**	**35.8**	**31.0**	**25.8**	**18.8**	**13.8**	
	0.4% MCWB	**8.2**	**10.9**	**13.2**	**16.4**	**20.9**	**24.6**	**23.5**	**25.2**	**21.3**	**18.3**	**15.0**	**8.8**	
	2% DB	**11.2**	**14.9**	**20.3**	**24.0**	**29.0**	**32.9**	**33.2**	**33.7**	**29.1**	**23.3**	**16.2**	**11.2**	
	2% MCWB	**7.1**	**9.2**	**12.5**	**15.5**	**19.4**	**23.3**	**23.6**	**23.8**	**20.6**	**17.8**	**12.9**	**8.8**	
	5% DB	**9.2**	**12.8**	**18.6**	**22.2**	**27.0**	**31.1**	**32.1**	**32.0**	**27.8**	**21.9**	**14.9**	**10.0**	
	5% MCWB	**6.4**	**7.9**	**11.9**	**14.4**	**18.5**	**22.3**	**23.2**	**22.9**	**20.0**	**16.8**	**12.4**	**8.1**	
	10% DB	**8.0**	**10.9**	**16.7**	**20.4**	**25.1**	**29.7**	**31.0**	**30.5**	**25.9**	**20.1**	**13.7**	**8.9**	
	10% MCWB	**5.9**	**7.1**	**11.0**	**13.7**	**17.6**	**21.4**	**22.4**	**22.2**	**18.8**	**16.2**	**11.9**	**7.4**	
Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures	0.4% WB	**10.1**	**11.5**	**15.1**	**17.6**	**21.7**	**26.2**	**26.4**	**27.0**	**23.2**	**19.8**	**15.6**	**11.2**	
	0.4% MCDB	**12.4**	**16.6**	**20.1**	**23.9**	**29.7**	**33.3**	**32.3**	**33.9**	**28.6**	**22.6**	**17.0**	**12.3**	
	2% WB	**8.2**	**9.9**	**13.6**	**16.1**	**20.3**	**24.5**	**25.1**	**25.2**	**22.1**	**19.0**	**14.1**	**9.7**	
	2% MCDB	**9.6**	**13.3**	**18.1**	**22.3**	**27.0**	**30.5**	**31.0**	**31.1**	**26.8**	**21.8**	**15.3**	**10.5**	
	5% WB	**7.1**	**8.7**	**12.5**	**15.2**	**19.3**	**23.3**	**24.1**	**24.1**	**21.0**	**18.1**	**13.1**	**8.5**	
	5% MCDB	**8.4**	**11.3**	**17.0**	**20.8**	**25.4**	**29.1**	**30.0**	**29.6**	**25.4**	**20.9**	**14.3**	**9.4**	
	10% WB	**6.1**	**7.7**	**11.5**	**14.3**	**18.3**	**22.3**	**23.3**	**23.1**	**20.0**	**17.0**	**12.1**	**7.4**	
	10% MCDB	**7.5**	**9.7**	**15.7**	**19.1**	**23.9**	**27.8**	**29.2**	**28.5**	**24.1**	**19.3**	**13.4**	**8.3**	
Mean Daily Temperature Range		MDBR	**7.0**	**8.5**	**10.2**	**9.8**	**10.0**	**10.2**	**10.5**	**10.3**	**9.8**	**7.9**	**6.4**	**6.2**
	5% DB MCDBR	**9.8**	**12.9**	**14.0**	**13.1**	**13.0**	**11.9**	**11.4**	**11.9**	**11.8**	**10.6**	**8.5**	**8.2**	
	5% DB MCWBR	**6.5**	**8.0**	**7.3**	**6.0**	**5.6**	**5.4**	**4.9**	**4.8**	**4.8**	**5.7**	**5.5**	**5.8**	
	5% WB MCDBR	**7.8**	**10.8**	**11.8**	**11.4**	**11.5**	**11.1**	**10.5**	**11.1**	**10.2**	**8.8**	**6.4**	**5.8**	
	5% WB MCWBR	**5.7**	**7.1**	**6.6**	**5.7**	**5.6**	**5.6**	**5.0**	**5.1**	**4.8**	**5.7**	**5.5**	**5.8**	
Clear Sky Solar Irradiance	taub	**0.349**	**0.377**	**0.423**	**0.465**	**0.462**	**0.484**	**0.465**	**0.456**	**0.450**	**0.433**	**0.378**	**0.343**	
	taud	**2.379**	**2.270**	**2.147**	**2.062**	**2.124**	**2.108**	**2.168**	**2.197**	**2.184**	**2.187**	**2.309**	**2.402**	
	Ebn at noon	**743**	**785**	**795**	**795**	**812**	**794**	**805**	**795**	**761**	**707**	**692**	**708**	
	Edn at noon	**77**	**102**	**132**	**156**	**151**	**155**	**144**	**135**	**126**	**110**	**82**	**68**	
All-Sky Solar Radiation	RadAvg	**1.45**	**2.24**	**3.57**	**4.51**	**5.58**	**6.43**	**6.56**	**5.55**	**4.15**	**2.43**	**1.44**	**1.21**	
	RadStd	**0.21**	**0.33**	**0.46**	**0.50**	**0.45**	**0.37**	**0.40**	**0.34**	**0.28**	**0.38**	**0.25**	**0.17**	

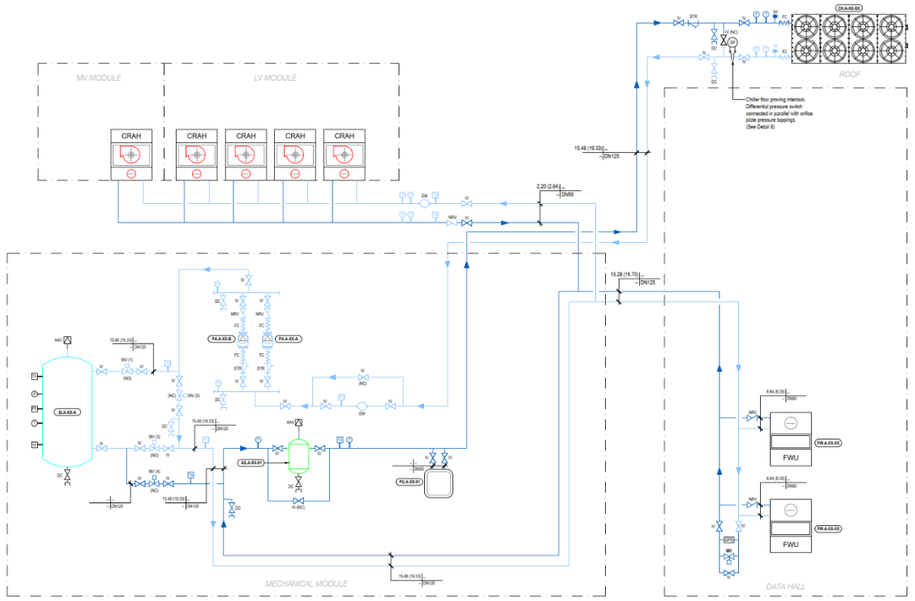
Historical Trends

	DBAvg	Heating		Cooling			Degree-Days			
		99% DB	99% DP	1% DB	1% WB	1% DP	HDD10.0	HDD18.3	CDD10.0	CDD18.3
Station Only	**N/A**	**N/A**	**N/A**	**N/A**	**-1.14**	**-1.61**	**N/A**	**N/A**	**N/A**	**N/A**
Regional (0 neighbors)	**+0.35**	**N/A**	**N/A**	**+0.66**	**+0.38**	**+0.29**	**N/A**	**N/A**	**+61**	**+10**

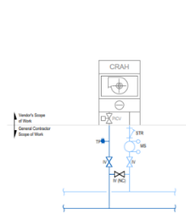
Appendix B Mechanical Schematics



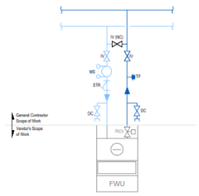
1 | Typical Electrical Power String Module Chilled Water System
SCALE: NTS



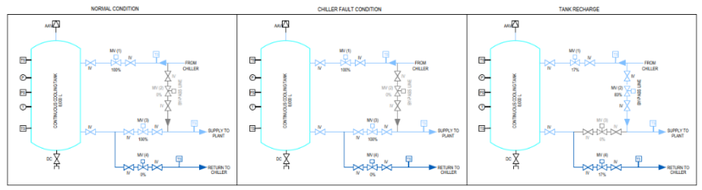
2 | A1 and B1 Electrical Power String Module Chilled Water System
SCALE: NTS



3 | Detail - Typical CRAH Valve Arrangement
SCALE: NTS



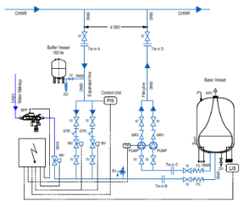
4 | Detail - Typical FWU Valve Arrangement
SCALE: NTS



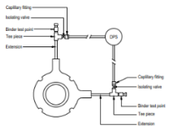
5 | Detail - System Configuration During Normal Operation And After Chiller Fault
SCALE: NTS

Valve Reference	Scenario			
	Normal	Chiller Fault	Tank Recharge	Status at Failure
MV (1)	100% Open	100% Open	17% Open	Fail open
MV (2)	Close	Close	83% Open	Fail closed
MV (3)	100% Open	100% Open	Close	Fail open
MV (4)	Close	Close	17% Open	Fail closed

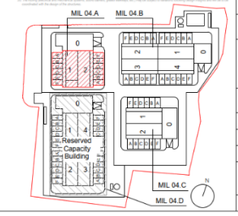
6 | Detail - Motorized Valves Modes of Operation
SCALE: NTS



7 | Detail - Dynamic Pressurisation Unit
SCALE: NTS



8 | Detail - Orifice Plate for Combined DPS and Binder Test Point
SCALE: NTS



Legend
Normal - (Failure) Ln [Normal - (Failure) mm
Normal - (Failure) Form [Pipe size mm

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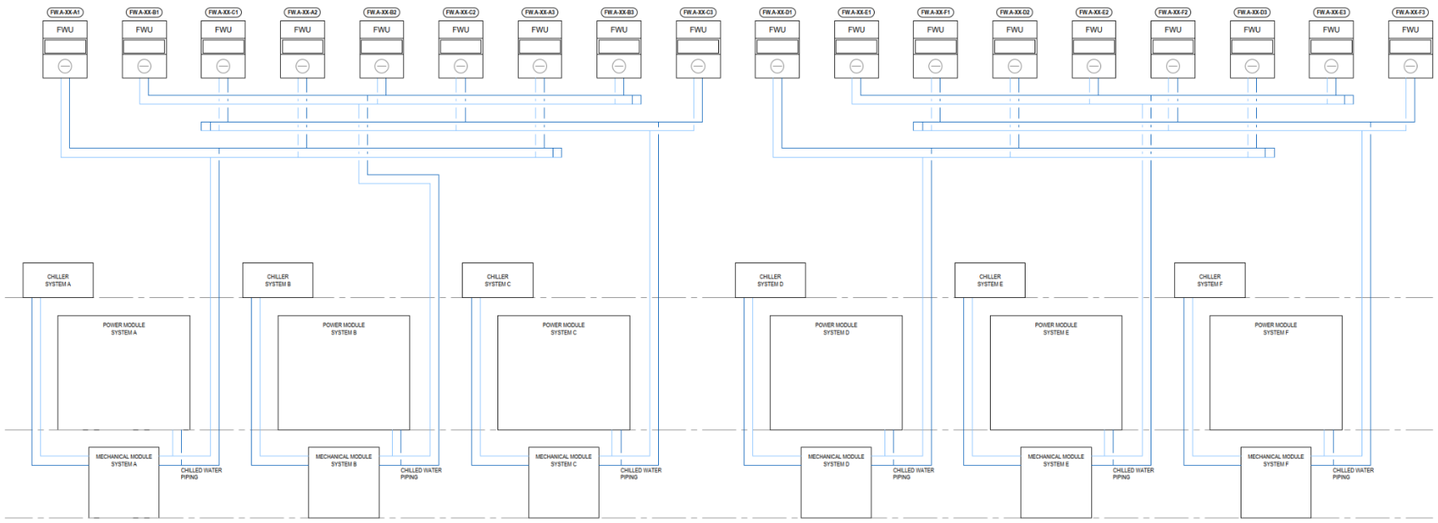
Ing. Roberta Cereda - iscritto all'Ordine degli Ing. di Brescia n°A 2809

OGGETTO / OBJECT:
RIBA4 - MIL 04.A

TITOLO / DESCRIPTION:
Cooling Schematic
Chilled Water
Building A

DISEGNATO DA: / DRAWN BY: L22/BS/N
CONTROLLATO DA: / CHECKED BY: L22/BS/N
DATA / DATE: 29/09/2023
SCALA / SCALE: NTS
NOME FILE / FILE NAME: 3604_EMA2082-U
COMMESSA / JOB: 3604
FORMATO / SHEET: A0
TAVOLA / DRAWING:
EMA2082-U
DATA REV.:
REV.:

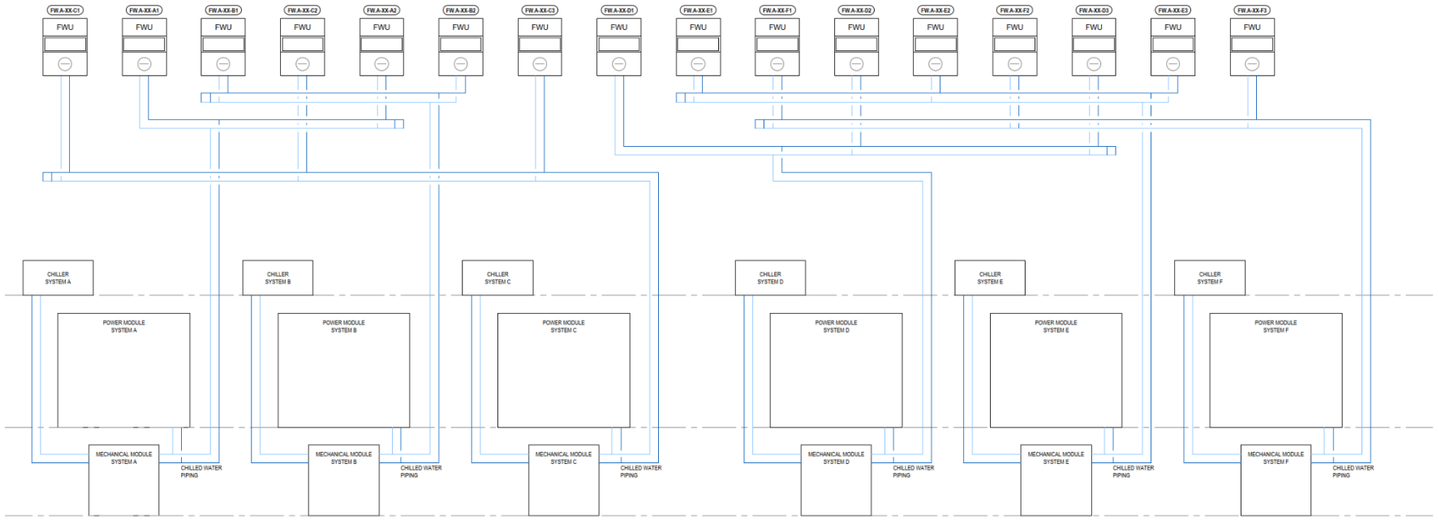


1 | Typical 5 MW Data Hall Chilled Water Schematic

SCALE: NTS

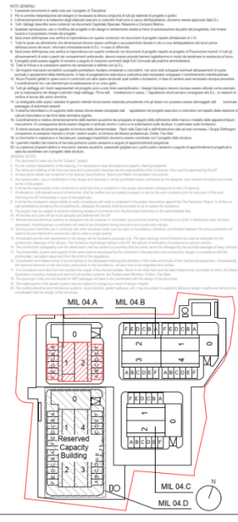
Notes

1. Schematic shows chilled water distribution strategy only. For pipe sizes and flow rates refer to drawing no. 3604_EMA2082-U.



2 | Typical 4.2 MW Data Hall Chilled Water Schematic

SCALE: NTS



REV	DATA / DATE	DESCRIZIONE / DESCRIPTION

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OGGETTO / OBJECT:
RIBA4 - MIL 04.A

TITOLO / DESCRIPTION:
Cooling Schematic
Typical Data Hall Chilled Water
Building A

DISEGNATO DA: DRAWN BY:	CONTROLLATO DA: CHECKED BY:
L22/B&W	
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Appendix C Typical Metering Strategy

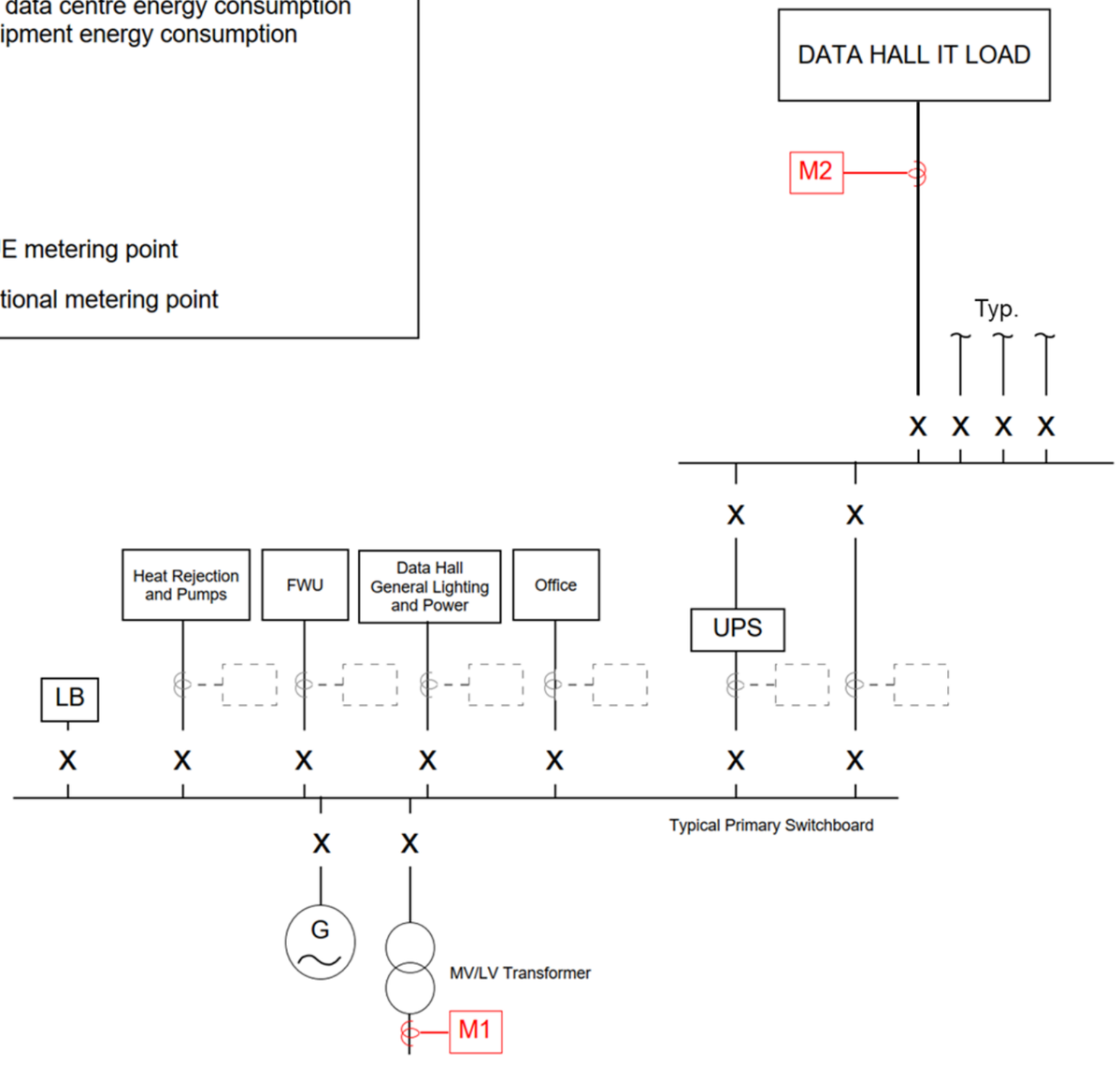
PUE = Power Usage Effectiveness
E_{DC} = Total data centre energy consumption
E_{IT}= IT equipment energy consumption

$$PUE = \frac{E_{DC}}{E_{IT}}$$

E_{DC} = M1
E_{IT} = M2

M# PUE metering point

Optional metering point



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Typical Metering Strategy

Appendix D Mechanical Energy Consumption

Critical Cooling Calculations

Input data:

Total cooling load	47300 kW
Total IT room area	8628 m²
ACC power consumption	35845213 kWh/a
CHW temperature, flow	20 °C
CHW temperature, return	30 °C
FWU supply air temperature	25 °C
Data hall room temperature	25 °C
Approach temperature (CHW - FWU)	4-5 K

Redundancy at N+1 (i.e. no failure or planned maintenance)

Temperature (°C)	Operation hours	Free cooling capacity per chiller (kW)	No. of active compressors (%)	ACC Abs Power (kWh)
-10.0	2	1000	-	1143
-9.0	3	1000	-	1752
-8.0	4	1000	-	2410
-7.0	8	1000	-	4900
-6.0	12	1000	-	7554
-5.0	30	1000	-	19192
-4.0	33	1000	-	21600
-3.0	47	1000	-	31460
-2.0	70	1000	-	47846
-1.0	108	1000	-	75640
0.0	179	1000	-	128931
1.0	192	1000	-	143640
2.0	221	1000	-	173758
3.0	265	1000	-	254479
4.0	318	1000	-	470023
5.0	344	1000	-	549385
6.0	389	1000	-	690920
7.0	328	1000	-	718948
8.0	290	758.3	30 | -	871962
9.0	299	742.5	32 | -	912980
10.0	340	725.1	34 | -	1061762
11.0	279	706.4	36 | -	894432
12.0	291	686.4	38 | -	947984
13.0	278	665.6	40 | -	931707
14.0	278	644.9	43 | -	967588
15.0	299	623.7	45 | -	1092068
16.0	307	601.1	48 | -	1209848
17.0	354	564.8	53 | -	1538047
18.0	321	521	60 | -	1549510
19.0	309	477.5	67 | -	1675335
20.0	307	425.4	75 | -	1913504
21.0	321	369.6	85 | -	2277933
22.0	346	316.7	95 | -	2570264
23.0	282	295.4	50 | 50	1944847
24.0	285	253.5	50 | 50	1986926
25.0	235	209.4	50 | 50	1656578
26.0	192	161.8	50 | 50	1411872
27.0	156	0	51 | 75	1265459
28.0	134	0	53 | 75	1123998
29.0	135	0	54 | 75	1165992
30.0	96	0	56 | 75	856079
31.0	58	0	57 | 75	531511
32.0	12	0	59 | 75	114248
33.0	3	0	61 | 75	29200
			Total	**35845213 kWh**

CHW Pump Power

The pump system flow rate stated below is based on total thermal load of 1000 kW. The pump is selected based on the peak maximum flow rate, however, at N+1 operation, the pump will run at lower speed as the required flow is shared by the extra pumpset. The pump will also ramp down if the required cooling load is reduced.

IT load %	25%	50%	75%	100%
Pump flow rate (kg/s)	6.0	12.0	17.9	23.9
Power consumption (kW)	4.5	6.0	7.8	10.5
Pump qty	36	36	36	36
Total Power (kW)	160.3	215.3	279.1	376.8

Fan Wall Power

The fan wall unit (FWU) is selected based on maximum cooling capacity of 358 kW each. The FWU is selected based on the peak maximum cooling capacity at N-units, however, at N+3 operation, the fan will run at lower speed as the required cooling load is shared with the extra units. The fan will also ramp down if the required IT load is reduced.

IT load %	25%	50%	75%	100%
Cooling required per unit (kW)	75	150	225	300
Power consumption per unit (kW)	0.2	1.8	6.2	14.6
FWU qty	105	105	105	105
Total Power (kW)	23.9	191.4	646.0	1531.3

Appendix E Electrical Losses

Electrical equipment efficiency obtained from various manufacturers, note that these do not represent final procured equipment, but provide target efficiency criteria.

UPS Efficiency	% Load for UPS			
Manufacturer	**25%**	**50%**	**75%**	**100%**
Vertiv	96.40	96.80	96.70	96.30

TX Efficiency	% Load			
	25%	**50%**	**75%**	**100%**
Vertiv	0.78%	0.70%	0.82%	1.13%

Building A General Lighting and Small power

	Floor area (m²)	Lighting Load (W/m²)	Diversified Lighting Load	Small Power Load (W/m²)	Diversified Small Power Load	Total (W)
Data hall building Ground Floor						
Data Hall	2713	8	0.1	5	0.1	3527
MEP Gallery	1000	8	0.1	5	0.1	1300
Maintenance	136	7	0.1	5	0.1	163
Circulation	286	7	0.4	5	0.4	1373
Mechanical Plant room	482	7	0.1	5	0.1	578
Generator room	591	7	0.1	320	0.8	151741
Ground floor Admin building						
Office	459	8	0.5	20	0.5	6430
Circulation	313	7	0.4	5	0.4	1505
WC/Locker	92	9	0.4	10	0.4	697
Security	51	12	1	200	1	10884
Reception	94	8	0.5	20	0.5	1320
Mechanical Plant room	50	7	0.1	5	0.1	60
Storage	467	6	0.1	5	0.1	514
Break area	64	8	0.4	20	0.4	713
Technical Room	55	8	0.5	20	0.5	765
Cleaning closet	9	9	0.1	10	0.1	17
Loading Dock	155	10	0.8	10	0.5	2009
First floor Data centre building						
Switch rooms	930	8	0.1	5	0.1	1209
First floor Admin building						
Technical Room	603	8	0.5	20	0.5	8436
Circulation	356	7	0.4	5	0.4	1707
Office	557	8	0.5	20	0.5	7792
Storage	380	6	0.1	5	0.1	418
WC/Locker	64	9	0.4	10	0.4	487
Security	53	12	1	200	1	11327
Roof level						
Roof	6489	7	0.1			4542
					Total	**219512**

Building B General Lighting and Small power

	Floor area (m²)	Lighting Load (W/m²)	Diversified Lighting Load	Small Power Load (W/m²)	Diversified Small Power Load	Total (W)
Data hall building Ground Floor						
Data Hall	5752	8	0.1	5	0.1	7478
MEP Gallery	1944	8	0.1	5	0.1	2527
Circulation	510	7	0.4	5	0.4	2447
Mechanical Plant room	1118	7	0.1	5	0.1	1342
Generator room	1183	7	0.1	320	0.8	303727
Ground floor Admin building						
Office	12	8	0.5	20	0.5	168
Circulation	189	7	0.4	5	0.4	906
WC/Locker	63	9	0.4	10	0.4	479
Security	59	12	1	200	1	12508
Reception	105	8	0.5	20	0.5	1470
Mechanical Plant room	77	7	0.1	5	0.1	92
Storage	122	6	0.1	5	0.1	134
Technical Room	26	8	0.5	20	0.5	364
Cleaning closet	6	9	0.1	10	0.1	11
Loading Dock	203	10	0.8	10	0.5	2639
First floor Data centre building						
Switch rooms	2341	8	0.1	5	0.1	3044
First floor Admin building						
Technical Room	603	8	0.5	20	0.5	8436
Circulation	356	7	0.4	5	0.4	1707
Office	557	8	0.5	20	0.5	7792
Storage	380	6	0.1	5	0.1	418
WC/Locker	64	9	0.4	10	0.4	487
Security	53	12	1	200	1	11327
Roof level						
Roof	10000	7	0.1	0	0	7000
					Total	**363141**

Building C General Lighting and Small power

	Floor area (m²)	Lighting Load (W/m²)	Diversified Lighting Load	Small Power Load (W/m²)	Diversified Small Power Load	Total (W)
Data hall building Ground Floor						
Data Hall	2876	8	0.1	5	0.1	3739
MEP Gallery	972	8	0.1	5	0.1	1264
Maintenance	0	7	0.1	5	0.1	0
Circulation	0	7	0.4	5	0.4	0
Mechanical Plant room	924	7	0.1	5	0.1	1109
Generator room	592	7	0.1	320	0.8	151864
Ground floor Admin building						
Office	143	8	0.5	20	0.5	2002
Circulation	185	7	0.4	5	0.4	888
WC/Locker	63	9	0.4	10	0.4	477
Security	53	12	1	200	1	11236
Reception	173	8	0.5	20	0.5	2422
Mechanical Plant room	43	7	0.1	5	0.1	52
Storage	238	6	0.1	5	0.1	262
Break area	0	8	0.4	20	0.4	0
Technical Room	39	8	0.5	20	0.5	546
Cleaning closet	0	9	0.1	10	0.1	0
Loading Dock	139	10	0.8	10	0.5	1807
First floor Data centre building						
Switch rooms	930	8	0.1	5	0.1	1209
Switch rooms						
Technical Room	90	8	0.5	20	0.5	1260
Circulation	323	7	0.4	5	0.4	1549
Office	473	8	0.5	20	0.5	6622
Storage	263	6	0.1	5	0.1	289
WC/Locker	53	9	0.4	10	0.4	403
Security	44	12	1	200	1	9328
Roof level						
Roof	5776	7	0.1	0	0	4043
					Total	**202682**

Notes:

The load and diversity factor are based on B&W standard design allocations.

The diversify factor is based on normal working hours profile for the majority of activities (08:00 to 18:00, Monday to Friday) and reduced hours during weekend.

The lighting diversify factor has accounted for daylight dimming and PIR sensor control.

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